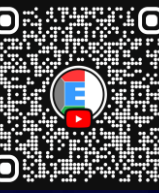


LET'S REVIEW SOIL CONSISTENCY



PAST CE BOARD EXAM: A saturated soil with a volume of 19.65cc has a mass of 36grams when the soil was dried, its volume and mass were 13.50cc and 25grams, respectively. What is the shrinkage limit of the soil?

Solution:

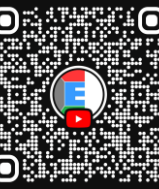
$$SL = \frac{m_1 - m_2}{m_2} - \frac{v_1 - v_2}{m_2} \times \rho_w$$

$$SL = \frac{36 - 25}{25} - \frac{19.65 - 13.50}{25} \times 1g/cc$$

$$SL = 19.40\%$$

SHRINKAGE LIMIT

$$SL_{solution} = \frac{m_1^{ara} - m_2^{ing}}{m_2^{oney}} - \frac{\rho_w^a (v_1^e - v_2^e)}{m_2^{odin!}}$$



PAST CE BOARD EXAM: The result are taken from the plastic limit test

Moist Unit Wt.	Dry Unit Wt.
128.6	105.4
141.4	116.8
132.6	109.6
134.5	111.2
136	113.4

Determine the plastic limit

Solution:

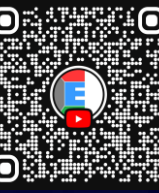
$$\gamma_m = \gamma_d(1 + \omega)$$

$$\omega = \left(\frac{\gamma_m}{\gamma_d}\right) - 1$$

Moist Unit Wt.	Dry Unit Wt.	Plastic Limit
128.6	105.4	
141.4	116.8	
132.6	109.6	
134.5	111.2	
136	113.4	

$$PL = (1/5)(0.22+0.208+0.2098+0.21+0.199)$$

PL = 0.21 or 21%



PAST CE BOARD EXAM: The result are taken from the cone penetration test

Moisture Content	Cone Penetration
42.5%	16mm
47.5%	17.5mm
58.1%	22.8mm
60%	26mm

Determine the liquid limit

Solution:

LL occurs at 20 penetration

Interpolation:

17.5	47.5%
20	LL
22.8	58.1%

$$\frac{\log(22.8) - \log(17.5)}{\log(20) - \log(17.5)} = \frac{58.1 - 47.5}{LL - 47.5}$$

LL = 52.85%

PAST CE BOARD EXAM: The result are taken from the Casagrande's cup method

No. of blows	Moisture Content
18	27
29	22

If PL = 16.5% and $\omega = 14.8\%$

Determine the following:

- Liquid Limit
- Plasticity Index
- Consistency Index
- Compression Index
- Activity of clay if there are 17% of clay sizes
- Liquidity Index

Solution:

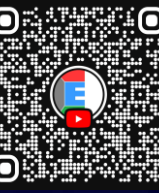
LL occurs at 25 blows

Interpolation:

18	27%
25	LL
29	22%

$$\frac{\log(29) - \log(18)}{\log(25) - \log(18)} = \frac{22 - 27}{LL - 27}$$

$$LL = 23.6\%$$



PAST CE BOARD EXAM: The result are taken from the Casagrande's cup method

No. of blows	Moisture Content
18	27
29	22

If $PL = 16.5\%$ and $\omega = 14.8\%$

Determine the following:

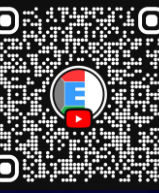
- Liquid Limit
- Plasticity Index**
- Consistency Index
- Compression Index
- Activity of clay if there are 17% of clay sizes
- Liquidity Index

Solution:

Plasticity Index

$$PI = LL - PL = 23.6 - 16.5 = \mathbf{7.1\%}$$

$$P_{usang}^{utang} I_{ring}^{na} = LL^{aki} - PL_a$$



PAST CE BOARD EXAM: The result are taken from the Casagrande's cup method

No. of blows	Moisture Content
18	27
29	22

If PL = 16.5% and $\omega = 14.8\%$

Determine the following:

- Liquid Limit
- Plasticity Index
- Consistency Index
- Compression Index
- Activity of clay if there are 17% of clay sizes
- Liquidity Index

Solution:

Plasticity Index

$$PI = LL - PL = 23.6 - 16.5 = 7.1\%$$

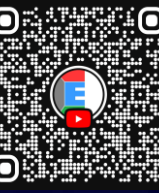
Consistency Index

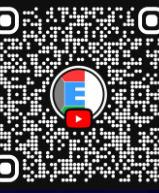
$$LL - w = CIPI$$

$$23.6 - 14.8 = (CI) (7.1)$$

$$CI = 1.24$$

$$PAG \quad LL^i - w_{ala} = \frac{CIPI}{CP | \text{Cellphone}}$$





PAST CE BOARD EXAM: The result are taken from the Casagrande's cup method

No. of blows	Moisture Content
18	27
29	22

If $PL = 16.5\%$ and $\omega = 14.8\%$

Determine the following:

- Liquid Limit
- Plasticity Index
- Consistency Index
- Compression Index**
- Activity of clay if there are 17% of clay sizes
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Plasticity Index

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Consistency Index

$$LL - w = CIPI$$

$$23.6 - 14.8 = (CI) (7.1)$$

$$CI = 1.24$$

Compression Index

$$Cc = 0.009(LL-10)$$

$$Cc = 0.009(23.6-10) = \mathbf{0.1224}$$

PAST CE BOARD EXAM: The result are taken from the Casagrande's cup method

No. of blows	Moisture Content
18	27
29	22

If $PL = 16.5\%$ and $\omega = 14.8\%$

Determine the following:

- Liquid Limit
- Plasticity Index
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- Compression Index
- Activity of clay if there are 17% of clay sizes
- Liquidity Index

Solution:

Plasticity Index

$$PI = LL - PL = 23.6 - 16.5 = 7.1\%$$

Consistency Index

$$LL - w = CIPI$$

$$23.6 - 14.8 = (CI) (7.1)$$

$$CI = 1.24$$

Compression Index

$$C_c = 0.009(LL - 10)$$

$$C_c = 0.009(23.6 - 10) = 0.1224$$

Activity of Clay

$$A = PI/\mu = 7.1/17 = 0.418$$


$$P_{\text{ara}} \underbrace{I/\mu}_{\text{iyo}} = A_{\text{ng laban nato!}}$$

PAST CE BOARD EXAM: The result are taken from the Casagrande's cup method

No. of blows	Moisture Content
18	27
29	22

If PL = 16.5% and $\omega = 14.8\%$

Determine the following:

- Liquid Limit
- Plasticity Index
- Consistency Index
- Compression Index
- Activity of clay if there are 17% of clay sizes
- Liquidity Index**

$$PILI = \omega_{aL} - PL_a$$

Note: A bracket connects the word "minus" from the list to the minus sign in the equation.

Solution:

Plasticity Index

$$PI = LL - PL = 23.6 - 16.5 = 7.1\%$$

Consistency Index

$$LL - w = CIPI$$

$$23.6 - 14.8 = (CI) (7.1)$$

$$CI = 1.24$$

Compression Index

$$Cc = 0.009(LL-10)$$

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Activity of Clay

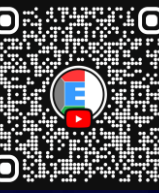
$$A = PI/\mu = 7.1/17 = 0.418$$

Liquidity Index

$$PILI = w - PL$$

$$7.1LI = 14.8 - 16.5$$

$$LI = -0.24$$



PAST CE BOARD EXAM: The result are taken from the Casagrande's cup method

No. of blows	Moisture Content
18	27
29	22

If PL = 16.5% and $\omega = 14.8\%$

Determine the following:

- Liquid Limit
- Plasticity Index
- Consistency Index
- Compression Index
- Activity of clay if there are 17% of clay sizes
- Liquidity Index

Solution:

Plasticity Index

$$PI = LL - PL = 23.6 - 16.5 = 7.1\%$$

Consistency Index

$$LL - w = CIPI$$

$$23.6 - 14.8 = (CI) (7.1)$$

$$CI = 1.24$$

Compression Index

$$C_c = 0.009(LL-10)$$

$$C_c = 0.009(23.6-10) = 0.1224$$

Activity of Clay

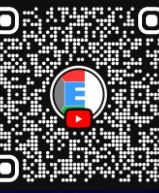
$$A = PI/\mu = 7.1/17 = 0.418$$

Liquidity Index

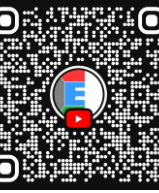
$$PILI = w - PL$$

$$7.1LI = 14.8 - 16.5$$

$$LI = -0.24$$



TEST YOURSELF



GI

SITUATION 2:

The plastic limit and liquid limit of a soil sample are 20.1% and 40% respectively.

4. Compute the plasticity index.

- a. 28.1%
- c. 60.1%

- ☒ b. 19.9%
- d. 15.6%

5. If the in-situ water content is 30%, compute the liquidity index.

- a. 36.5%
- c. 49.7%

- b. 32.1%
- d. 56.1%

6. Identify the condition of the soil.

- a. liquid
- c. dense

- b. plastic
- d. brittle solid

If $LI > 1.0$ soil behaves like liquid

If $LI < 0$, soil is brittle solid

If $LI > 0$ but less than 1.0, soil is plastic

$$PL = 20.1\%$$

$$LL = 40\%$$

$$\begin{aligned} PI &= LL - PL \\ &= 40 - 20.1 \\ &= 19.9\% \end{aligned}$$

$$w = 30\%$$

$$LI = ?$$

$$PI LI = w - PL$$

$$(19.9)(LI) = 30 - 20.1$$

$$LI = 0.497 = 49.7\%$$

$$0.497 > 0 \quad \therefore \text{plastic}$$
$$< 1$$

TEST YOURSELF

The following tabulated data are results of plastic limit and liquid limit test.

Plastic Limit test:

Test Number	1	2
Wt. of wet soil + container	21.23g	21.58g
Wt. of dry soil + container	19.95g	20.05g
Wt of container	12.03 g	12.85

Liquid Limit test:

Test Number	1	2	3	4
Wt. of wet soil + container	23.1 4g	22.1 8g	23.7 1g	22.9 1g
Wt. of dry soil + container	21.2 4g	19.9 5g	20.3 6g	19.2 5 g
Wt of container	12.7 5g	13.2 5g	13.1 6g	13.8 5g
# of blows	35	29	20	15

Natural water content test:

Test Number	1	2
Wt. of wet soil + container	16.89g	16.91g
Wt. of dry soil + container	14.82g	14.45g
Weight of container	7.85g	7.55g

1. Which of the following gives the plastic limit of the soil?

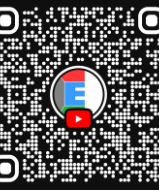
- a. 14.5 %
- b. 10.5 %
- c. 25.4 %
- d. 18.5 %

2. Which of the following gives the liquid limit of the soil?

- a. 52 %
- b. 39 %
- c. 32 %
- d. 48 %

3. Which of the following gives the liquidity index of the soil?

- a. 0.862
- b. 0.725
- c. 0.679
- d. 0.514



TEST YOURSELF

The following tabulated data are results of plastic limit and liquid limit test.

Plastic Limit test:

Test Number	1	2
Wt. of <u>wet soil + container</u>	21.23g	21.58g
Wt. of <u>dry soil + container</u>	19.95g	20.05g
Wt of <u>container</u>	12.03 g	12.85

1. Which of the following gives the plastic limit of the soil?

- a. 14.5 %
- b. 10.5 %
- c. 25.4 %
- d. 18.5 %

$$w = \frac{W_w}{W_s} = \frac{\text{Wt. of Wet Soil + Container} - \text{Wt. of Dry Soil + Container}}{\text{Wt. of Dry Soil + Container}}$$

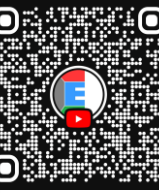
$$W_s = \text{Wt. of Dry Soil + Container} - \text{Wt. of Container}$$

$$W_t = \text{Wt. of Wet Soil + Container} - \text{Wt. of Container}$$

$$W_w = W_t - W_s$$

$$w_{PL} = 18.7\%$$

TEST YOURSELF



Liquid Limit test:

Test Number	1	2	3	4
Wt. of wet soil + container	23.1 4g	22.1 8g	23.7 1g	22.9 1g
Wt. of dry soil + container	21.2 4g	19.9 5g	20.3 6g	19.2 5g
Wt of container	12.7 5g	13.2 5g	13.1 6g	13.8 5g
# of blows	35	29	20	15

LL occurs @ 25 blows

$$W = \frac{W_w}{W_s} = \left[\frac{\text{Wt. of Wet Soil} + \text{Container}}{\text{Wt. of Dry Soil} + \text{Container}} \right] - \left[\frac{\text{Wt. of Container}}{\text{Wt. of Container}} \right]$$

$$\left[\frac{\text{Wt. of Dry Soil} + \text{Container}}{\text{Wt. of Container}} \right]$$

2. Which of the following gives the liquid limit of the soil?

a. 52 %

b. 39 %

c. 32 %

d. 48 %

TEST YOURSELF

Natural water content test:

Test Number	1	2
Wt. of wet soil + container	16.89g	16.91g
Wt. of dry soil + container	14.82g	14.45g
Weight of container	7.85g	7.55g

1. Which of the following gives the plastic limit of the soil?

- a. 14.5 %
- c. 25.4 %

b. 10.5 %

d. 18.5 %

2. Which of the following gives the liquid limit of the soil?

a. 52 %

c. 32 %

b. 39 %

d. 48 %

3. Which of the following gives the liquidity index of the soil?

a. 0.862

c. 0.679

b. 0.725

d. 0.514

$$PI LI = w - PL$$

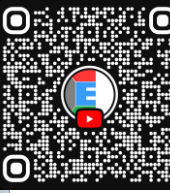
$$(LL - PL)(LI) = w - PL$$

$$LI = \frac{w - PL}{LL - PL}$$

$$LI = \frac{32.7 - 18.7}{38.6 - 18.7}$$

$$= 0.7$$

$$w = 32.7\%$$



TEST YOURSELF

PROBLEM 6:

A shrinkage limit test on a clay soil gave the following data:

wt. of shrinkage dish & saturated soil cake	38.78 g
wt. of shrinkage dish & oven dry soil cake	30.46 g
wt. of shrinkage dish	10.65 g
vol. of shrinkage dish	16.29 cm ³
total vol. of oven dry soil cake	10.0 cm ³

Compute the shrinkage limit.

Hint: Assume that the total volume of the dry soil cake is equal to the total volume at shrinkage limit.

- a. 15.4%
- c. 11.2 %

- b. 10.2%
- d. 12.7 %

$$SL = \frac{m_1 - m_2}{m_2} \cdot \frac{\rho_w (V_1 - V_2)}{m_2}$$

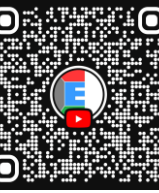
$$m_1 = 38.78 - 10.65 \quad (\text{wet soil})$$

$$m_2 = 30.46 - 10.65 \quad (\text{dry soil})$$

$$V_1 = 16.29 \text{ cc} \quad (\text{wet soil})$$

$$V_2 = 10.0 \text{ cc} \quad (\text{dry soil})$$

$$SL =$$



PAST CE BOARD EXAM:

A clay has the following Atterberg limits

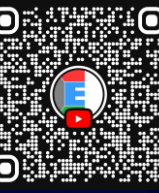
Liquid Limit = 60%

Plastic Limit = 40%

Shrinkage Limit = 25%

The clay shrinks from 15cc to 9.57cc when the moisture content is decreased from the liquid limit to the shrinkage limit. What is the dry specific gravity of the clay?

A) 2.73 B) 2.89 C) 2.62 D) 2.40





$$15 - 9.57 = 5.43$$

$$V_S = 5.69cc$$



PAST CE BOARD EXAM: A clay has the following Atterberg limits

Liquid Limit = 60%

Plastic Limit = 40%

Shrinkage Limit = 25%

The clay shrinks from 15cc to 9.57cc when the moisture content is decreased from the liquid limit to the shrinkage limit. What is the dry specific gravity of the clay?

$$\omega = \frac{W_W}{W_S} = \frac{\gamma_w V_W}{\gamma_w G_S V_S} = \frac{V_W}{G_S V_S}$$

LL=60%

Natural water content

$$V_T = 15\text{cc} = V_a + V_w + V_s$$

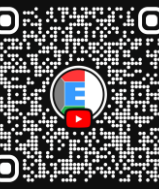
$$15\text{cc} = 0 + V_w + 5.69\text{cc}$$

$$V_w = 9.31\text{cc}$$

$$\omega = \frac{V_W}{G_S V_S}$$

$$0.60 = \frac{9.31}{G_S (5.69)}$$

$$G_S = 2.727$$





LET'S REVIEW

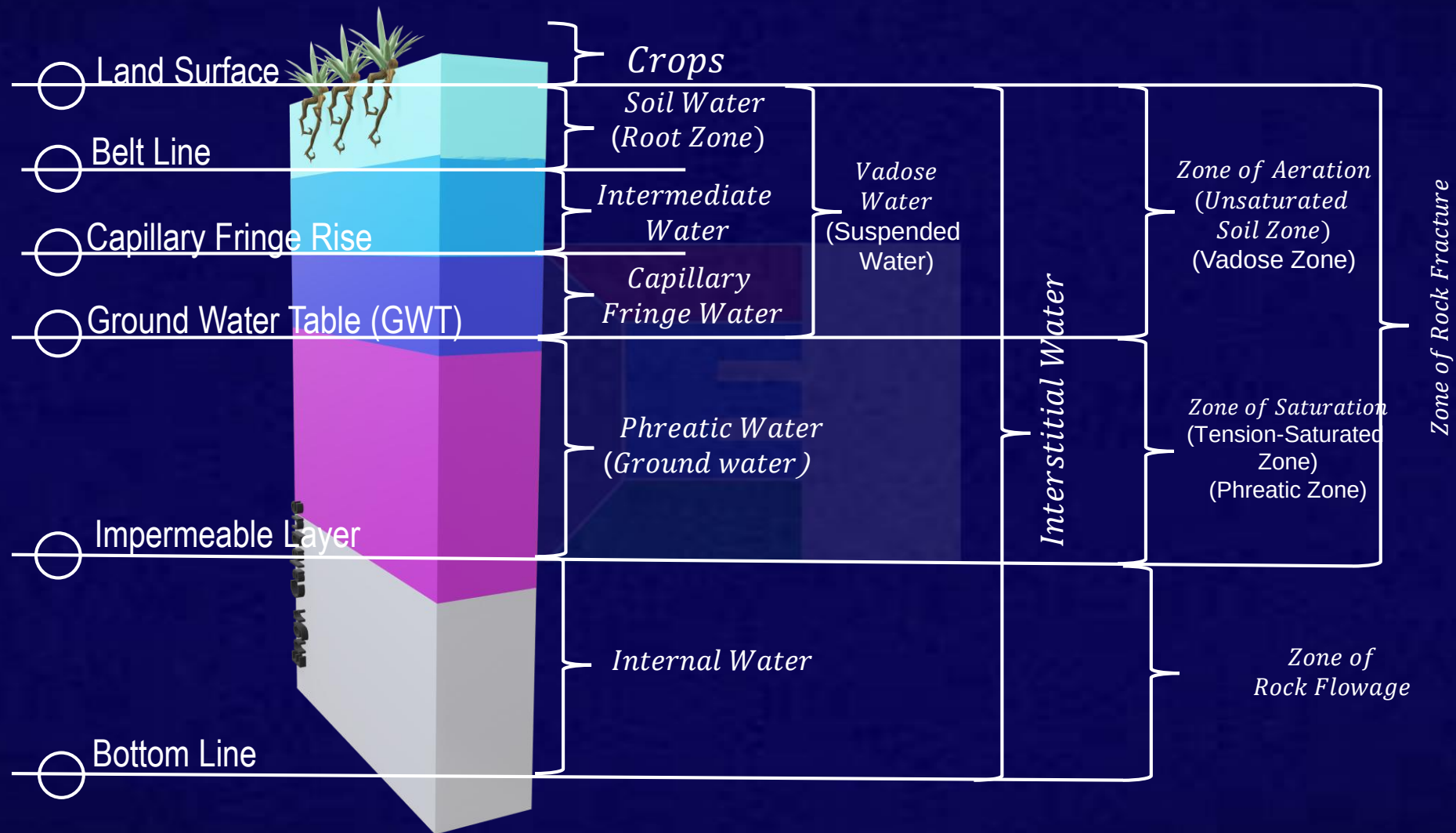
SOIL PERMEABILITY

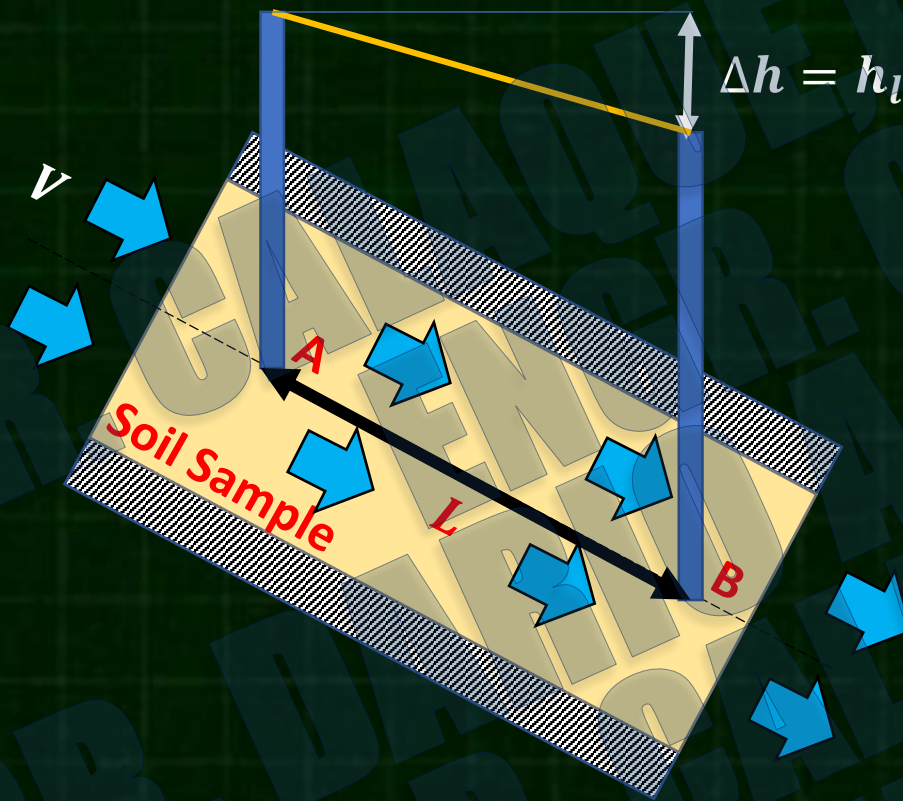
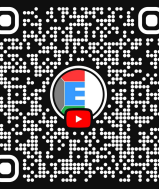
ENGR. DARIO A. CALAQUE, JR.



LET'S REVIEW

MOVEMENT OF WATER THROUGH SOIL



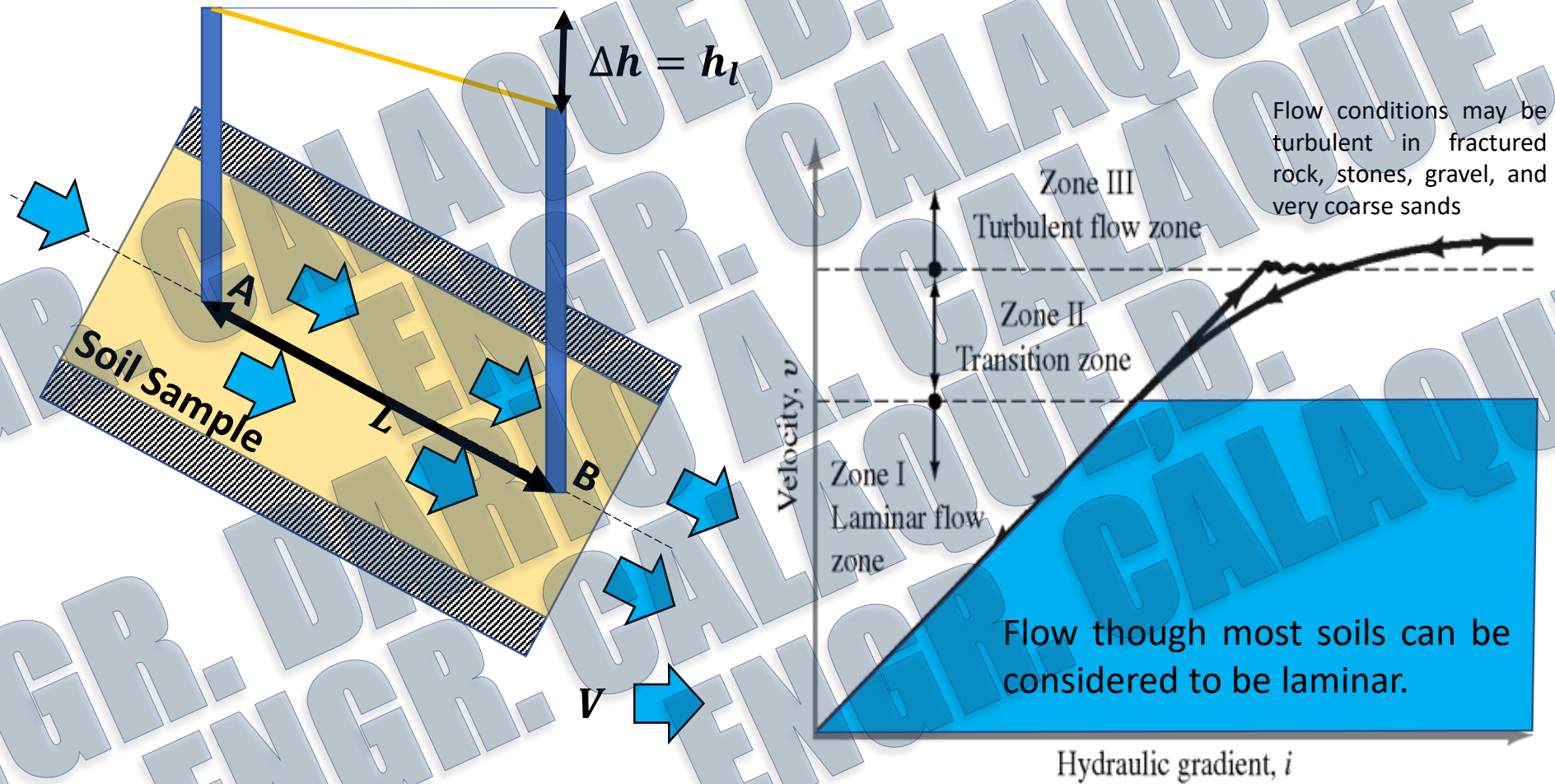
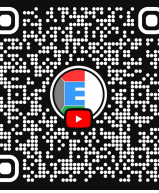


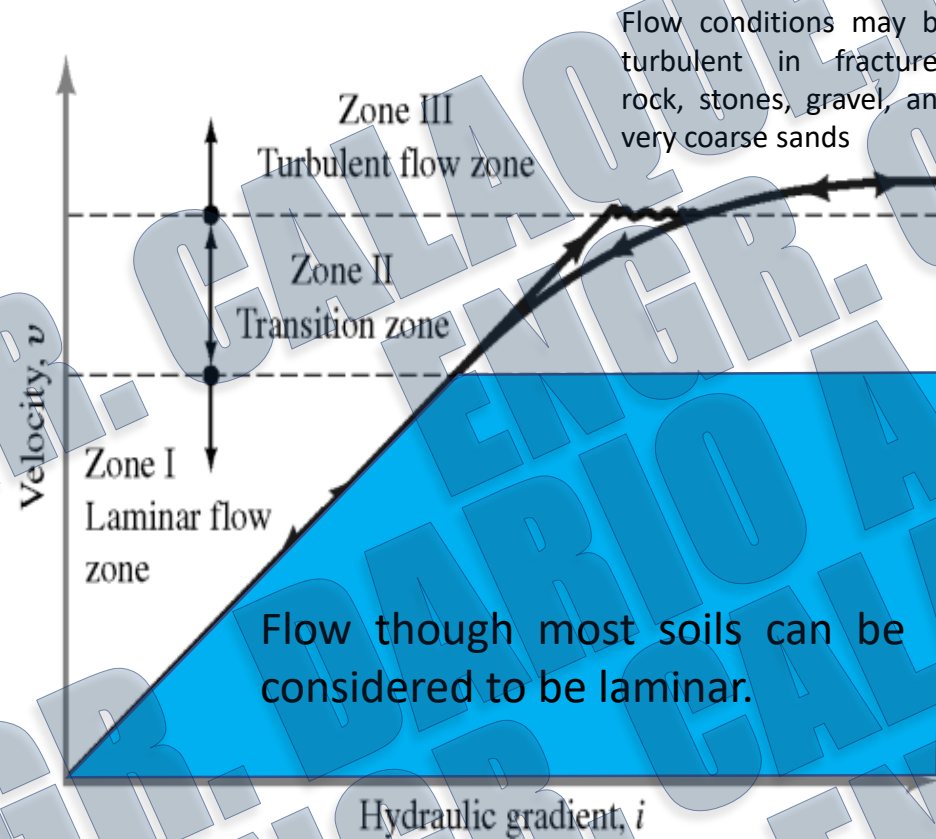
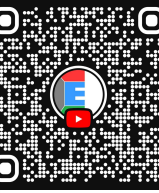
Hydraulic Gradient

Head loss per unit length is:

$$i = \frac{\Delta h}{L} = \frac{h_l}{L}$$

where: i = hydraulic gradient
 Δh = head loss between points of interest
 L = distance between points of interest



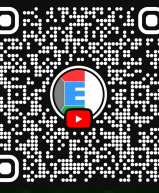


Therefore a linear relationship between velocity and hydraulic gradient.

$$v \propto i$$

1856 Darcy published a simple equation for the discharge velocity through saturated soils

$$v = k i$$



Henry Philibert Gaspard Darcy

DARCY'S LAW

$$v = k i$$

DARCY'S LAW

discharge velocity

- Quantity of water flowing in unit time through a unit gross cross sectional area of soil at right angles to the direction of flow
- Does not account for flow through soil voids

$$v = k i$$

hydraulic gradient

hydraulic conductivity

Depends on:

- Type of fluid (water vs molasses)
 - Viscosity, density
- Pore size distribution
- Grain size distribution
- Void ratio
- Particle shape
- Degree of saturation
- Size of double layer (clay type)



Henry Philibert Gaspard Darcy

DARCY'S LAW

$$v = k i$$

hydraulic conductivity

Depends on:

- Type of fluid (water vs molasses)
 - Viscosity, density
- Pore size distribution
- Grain size distribution
- Void ratio
- Particle shape
- Degree of saturation
- Size of double layer (clay type)

Hydraulic Conductivity

$$k = \frac{K\rho g}{\eta} = \frac{K\gamma_w}{\eta}$$

where:

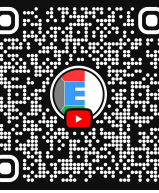
K = absolute permeability (L²)

ρ = density of fluid

g = gravitational constant

η = viscosity of fluid

γ_w = Unit weight of fluid



DARCY'S LAW

discharge velocity

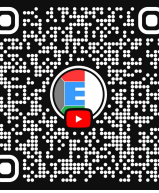
$$v = k i$$

hydraulic conductivity

Hydraulic Conductivity

Table 5.1 Typical values of hydraulic conductivity for saturated soils

Soil type	k (cm/sec)
Clean gravel	100–1
Coarse sand	1.0–0.01
Fine sand	0.01–0.001
Silty clay	0.001–0.00001
Clay	<0.000001



DARCY'S LAW

$$v = k i$$

hydraulic conductivity

Hydraulic Conductivity

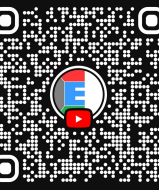
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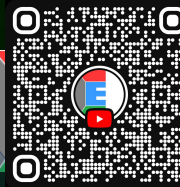
Soil type	k (cm/sec)
Clean gravel	100–1
Coarse sand	1.0–0.01
Fine sand	0.01–0.001
Silty clay	0.001–0.00001
Clay	<0.000001

Laboratory Measurement of Hydraulic Conductivity

Two of the many types of equipment for measuring permeability:

- 1) Constant-Head Permeameter
- 2) Variable-Head Permeameter





CONSTANT HEAD TEST

$$k = \frac{VL}{hAt}$$

DARCY'S LAW

$$v = k i$$

Where:

k = coefficient of permeability or hydraulic conductivity

V = volume or quantity of water collected

L = length of specimen

h = constant head causing flow

A = cross-sectional area of the specimen

t = duration of water collection

i = hydraulic gradient = h/L

v = discharge velocity

What hafen vela?

...Why u crying again?

1 know...vamfire! right?



Christopher Diwata

CONSTANT HEAD TEST

$$k = \frac{VL}{hAt}$$

DARCY'S LAW

$$v = k i$$



Christopher Diwata

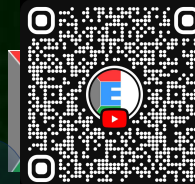
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...Why u crying again?

I know...vamfire! right?

$$w^{hAt}_{fen} = \frac{V_e L_a}{k_{rying} \text{ again?}}$$

$$i k_{now} = v_{amfire} \text{ right?}$$



CONSTANT HEAD TEST

$$k = \frac{VL}{hAt}$$

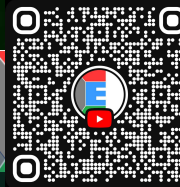
DARCY'S LAW

$$v = k i$$



$$k_a h_{umot} = \overset{sa}{V}_a \overset{ut}{L} / \underset{na\ maalat}{At}$$

$$i k_a = v_{astos!}$$



FALLING HEAD TEST

$$k_{ung} = \frac{a_{ng} L_{ove}}{A_y t_{rue}} \ln_{aging} \left(\frac{h_1^{o\text{-holding}}}{h_2^{ands}} \right) aYiee!$$

DARCY'S LAW

$$v = k i$$

Variable-Head Permeameter
(Falling Head Test)

hydraulic conductivity

Falling Head Test

$$q_{\text{soil}} = k \frac{h}{L} A$$

where:

k = soil hydraulic conductivity

h = total head loss

L = length of soil column resulting in head loss

A = soil column cross sectional area

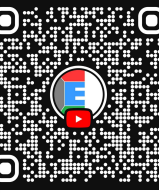
Continuity:

$$q_{\text{in}} = q_{\text{soil}}$$

$$Q = Av$$
$$v = ki$$

$$Q = Aki$$

$$Q = k \frac{h}{L} A$$



DARCY'S LAW

$$v = k i$$

Variable-Head Permeameter
(Falling Head Test)

hydraulic conductivity

Falling Head Test

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Falling Head Test

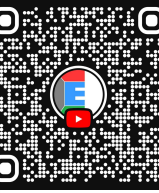
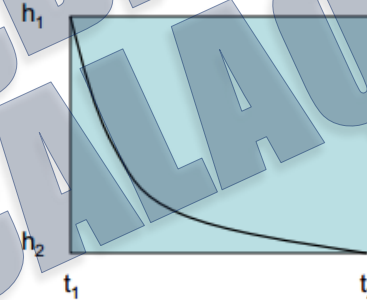
$$-a \frac{dh}{dt} = k \frac{h}{L} A$$

$$-a \frac{dh}{h} = k \frac{A}{L} dt$$

$$-a \int_{h_1}^{h_2} \frac{dh}{h} = k \frac{A}{L} \int_{t_1}^{t_2} dt$$

$$-a \ln \frac{h_1}{h_2} = k \frac{A}{L} t$$

$$k = 2.303 \frac{aL}{At} \log \frac{h_1}{h_2}$$



DARCY'S LAW

$$v = k i$$

hydraulic conductivity
Variable-Head Permeameter
(Falling Head Test)

Falling Head Test

Falling Head Test

$$-a \frac{dh}{dt} = k \frac{h}{L} A$$

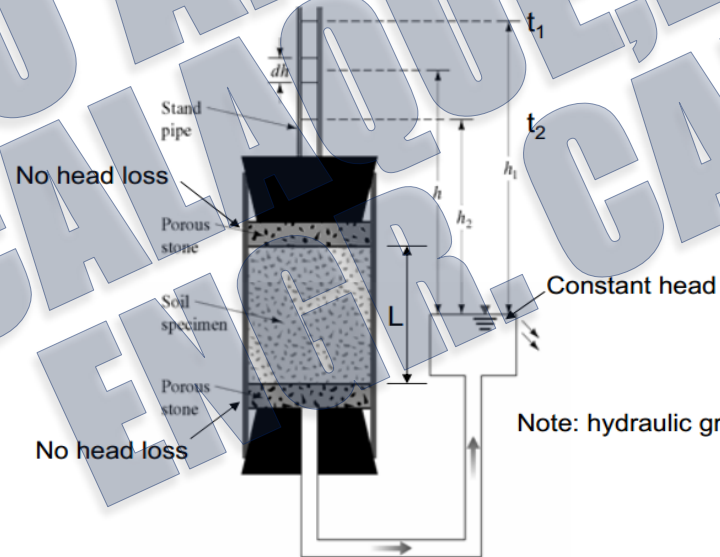
$$-a \frac{dh}{h} = k \frac{A}{L} dt$$

$$-a \int_{h_1}^{h_2} \frac{dh}{h} = k \frac{A}{L} \int_{t_1}^{t_2} dt$$

$$-a \ln \frac{h_1}{h_2} = k \frac{A}{L} t$$

$$k = 2.303 \frac{aL}{At} \log \frac{h_1}{h_2}$$

Falling Head Test



DARCY'S LAW

$$v = k i$$

hydraulic conductivity

K – Relations for Granular Soils

Recommend measuring K in the lab or in the field if it is critical.

K field measurement methods:

- Bail test
- Well pump test
- Permeameter
- Borehole packer test

Hazen Equation

$$k(\text{cm/s}) = cD_{10}^2$$

where:

c = a constant that varies from 1.0 to 1.5

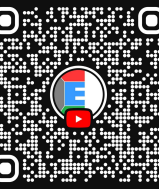
D_{10} = effective particle size for 10 percent passing (mm)

Equation works OK for clean loose sand.



Allen Hazen

DARCY'S LAW



seepage velocity

- Seepage velocity is significantly greater than the Darcy's discharge velocity.
- Seepage velocity is an average velocity through the pore voids
 - Higher velocities will occur in small pore throats
 - Low velocities in large pore throats

$$v_s = \frac{k i}{n}$$

n
porosity

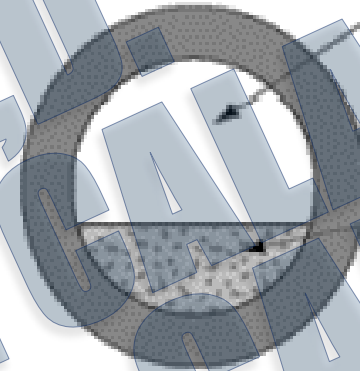
$$n = \frac{e}{1 + e}$$

Void ratio

DARCY'S LAW

seepage velocity

$$v_s = \frac{k i}{n} *$$



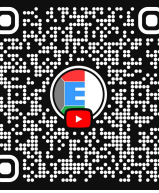
Area of void
in the cross
section = A_v

Area of soil
solids in the
cross section
= A_s

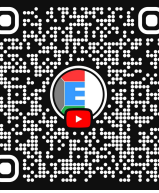
$$Q = v_s A_v$$

Flow rate

Area of void in the cross section

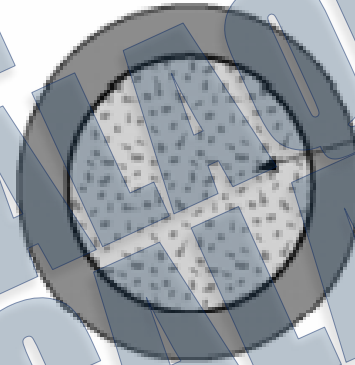


DARCY'S LAW



discharge velocity

$$v = k i *$$

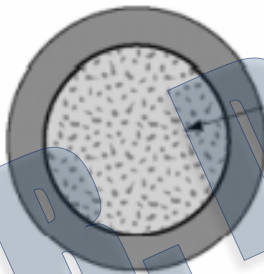


Area of
soil
specimen = A

Area of soil specimen

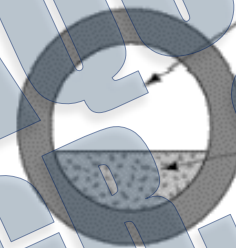
$$Q = v A$$

Flow rate



Area of
soil
specimen = A

=



Area of void
in the cross
section = A_v

Area of soil
solids in the
cross section
= A_s

$$v A = A_v v_s$$



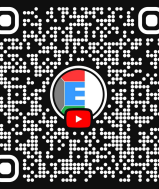
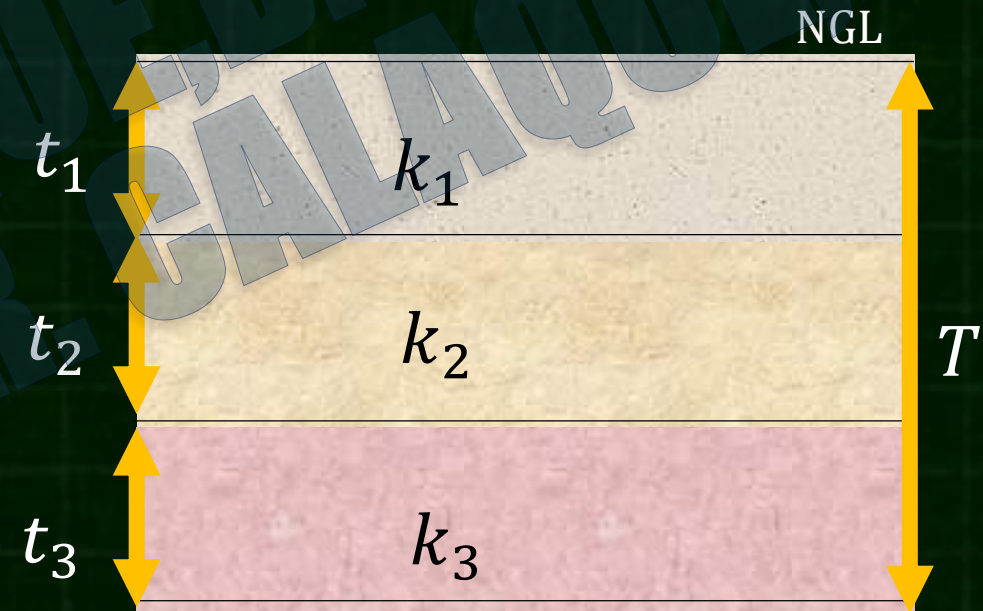
Nag kata kata lang
Nag taka taka lang
tong babaeng to.
Kay naka-igo pod!

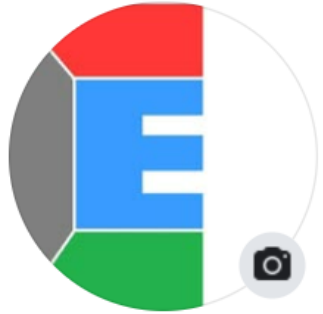
Equivalent Coefficient of Permeability
in Horizontal Flow, K_h

Nag... $K_h^a T^a = \sum k_a t_a$

Equivalent Coefficient of Permeability
in Vertical Flow, K_v

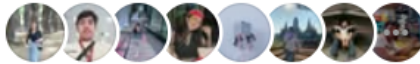
$\frac{T^a}{K_v^a} = \sum \frac{t_a}{k_a}$ tong babaeng to.
Kay naka-igo pod!





Excel, Android and Desktop Applications

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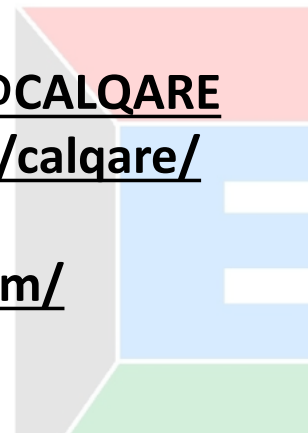


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